

THE COLLEGE OF EARTH AND MINERAL SCIENCES

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The Variation of the Angle of Internal
Friction with Size Consist for Mechanically -
Chipped Material

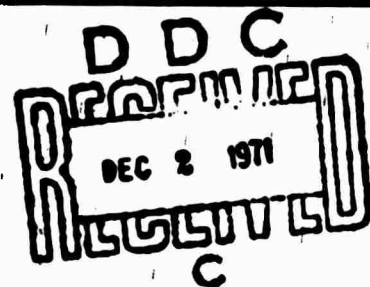
Report Number H0210027-1

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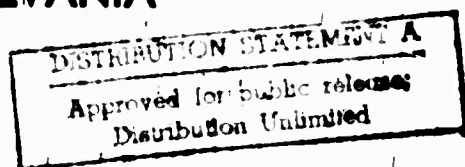
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12. ABSTRACT In order to improve aspects of materials handling in the rapid excavation process, research is underway to characterize the muck from mechanical tunnel boring machines. The specific project involves the correlation of the angle in internal friction, ϕ , to the size consist, often termed gradation, of this mechanically-chipped material. Existing references demonstrate that this angle depends upon mineral type, and for a given mineral type upon size of particles. Particle shape is usually a function of mineralogical character and is not as important a parameter in influencing this angle. The project investigators have visited nine tunnels and have samples from seven; rock types collected include granite, limestone, mica schist, sandstone, and shale. A facility for testing these specimens is being prepared and will consist of a flexible arrangement of 2.8 or 6-inch triaxial cells, pressure system, testing machine, and automated data collection system. The latter will insure the removal of personal bias from the data. Testing of samples can begin soon after			

DD FORM 1473 [a load cell is delivered.]

Security Classification

ITEM	ITEM I		ITEM II		ITEM III	
	NO.	QTY.	NO.	QTY.	NO.	QTY.
Rapid Excavation	8	3				
Materials Handling	8	3				
Angle of Internal Friction	7	3	6	0		
Size Consist	6	3	7	0		

Security Classification

THE PENNSYLVANIA STATE UNIVERSITY

COLLEGE OF EARTH AND MINERAL SCIENCES

Dedicated to education and research in mineral exploration, use, and conservation; understanding and development of materials; and the preservation of our environment.

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Mining Technology

ANALYTICAL AND STRUCTURAL STUDIES:

Wet Chemical Analysis of Silicate and Carbonate Rocks, X-ray Crystallography, Electron Microscopy and Diffraction, Electron Microprobe Analysis, and Spectroscopic and other instrumental Analysis

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Semi - Annual Technical Report

October 20, 1971

Report Summary

Abstract

In order to improve aspects of materials handling in the rapid excavation process, research is underway to characterize the muck from mechanical tunnel boring machines. The specific project involves the correlation of the angle of internal friction, ϕ , to the size consist, often termed gradation, of this mechanically-chipped material. Existing references demonstrate that this angle depends upon mineral type, and for a given mineral type upon size of particles. Particle shape is usually a function of mineralogical character and is not as important a parameter in influencing this angle. The project investigators have visited nine tunnels and have samples from seven; rock types collected include granite, limestone, mica schist, sandstone, and shale. A facility for testing these specimens is being prepared and will consist of a flexible arrangement of 2.8 or 6-inch triaxial cells, pressure system, testing machine, and automated data collection system. The latter will insure the removal of personal bias from the data. Testing of samples can begin soon after a load cell is delivered.

Technical Problems

The only problems encountered were those associated with machine delays at the operating sites. These were anticipated in the research program and did not hinder sample collection.

Equipment Purchases

Purchases have been restrained to those items specifically listed in the contract or its amendments. A complete list is contained in Appendix 1.

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The Variation of the Angle of Internal
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Semi - Annual Technical Report April - Oct. 1971

Introduction

The Project

Well-grounded ratiocination about urban crowding demonstrates that the sub-surface is imperfectly utilized. Technologies to improve this use are grouped in the phrase "Rapid Excavation". Among these disciplines, many of which are seen to be inefficient, is materials handling. This report is a consequence of a research project which has been funded in order to help improve materials handling in machine - driven tunnels. As described in the research proposal¹⁰, the specific purpose is to determine if the handling characteristics of the muck from boring machines working in hard rock vary with particle size. Intuition and previous research on natural materials (detailed in the next section) indicate that the existence of such a variation is quite likely. The characteristic under observation is the angle of internal friction; it is postulated that its value will drop as particle size increases.

The Problems

In order to perform this research two basic problems had to be resolved. These are the source of the samples and the method of determining the angle of friction. Accordingly, two lines of inquiry were pursued during the beginning of the project: location of active tunnel sites in the United States; and previous research into size effects on the angle of internal friction. From these inquiries, liaison was established with prospective field sites and equipment for the testing program was selected. The following sections detail these procedures.

Test System

The Shear Test

The angle of internal friction is a number, analogous to the coefficient of sliding friction, which relates the shear strength of a granular material to the normal force acting on this material. This angle, often named ϕ , is dependent upon a number of parameters: including the material's mineralogical composition, and, hence, angle of sliding friction; the shape and roughness of its particles; and, of course, its size consist. ϕ is normally determined in a direct-shear test or in a triaxial shear test. Both are routinely described in many textbooks on soil mechanics¹¹.

This study was undertaken because ϕ is, itself, an independent parameter in many materials handling equations, especially those dealing with gravity flow^{4, 8, 9}. Because ϕ is responsive to changes in the parameters listed above, it is useful as a muck handling quality number. In general, a low angle (with little cohesion) will result in an easier gravity transfer than a high angle. Consequently, a shear test, resulting in angle of internal friction and the degree of cohesion for a granular material, is a good way of establishing handling characteristics.

Inasmuch as the aim of the project is to determine ϕ for muck from boring machines and to see if it varies with particle size, a literature search was undertaken to select the best shear test and to locate any prior work on size effect. Luckily there were several articles that covered concisely those questions. One series of articles^{6, 7} described the effect on ϕ of varying particle shape, particle size, particle gradation, and particle mineralogy. The first conclusion made was of interest to equipment selection in the present project: triaxial shear was recommended over direct shear. Test conclusions were that ϕ increased with increasing

angularity and decreasing sphericity, with decreasing particle size, and that an amount of "flakey" mineralization can seriously alter a soil sample's triaxial analysis. Koerner describes a system for measuring particle sphericity. A slightly older paper⁵ investigated the effect of varying particle size and sample gradation on the angle of internal friction. The conclusion was similar -- stated inversely --, ϕ decreased with increased particle size, but up to a limit of about two millimeters. It was further concluded that the frictional component of ϕ , ϕ_f was independent of particle size and, perhaps, shape, and dependent on surface roughness and mineralogy. The variation in total ϕ was due to dilatational changes (porosity changes) and was called ϕ_d ; these changes varied with particle size and gradation.

The Equipment

The choice of test equipment needed to measure ϕ was made on the basis of the conclusions in the reviewed articles and on the availability of equipment. It was realized that boring-machine muck could be quite large in comparison to sand; consequently, it was postulated that the equipment must be able to handle a two-inch particle size. Some of the largest pieces collected even exceeded this size. Available on the market are both a six-inch (cell, not particle size) shear-box machine and triaxial cell. Because of theoretical considerations listed above, adaptability to present Penn State equipment, and the presence of the shear-box machine at the Pittsburgh Mining Research Center, it was decided to purchase a triaxial system for this project. It was recognized that there would be difficulties in measuring ϕ for a sample with large particles no matter which system was chosen. Degradation of sample, for instance, remains a major concern. It was felt that the triaxial cell would be more satisfactory in this respect. No reference could be found regarding particle

size vs cell size in the triaxial test; therefore one tangential study will examine this aspect. Information was found, however, that indicated that membrane penetration by large angular particles could be a problem. This, also, will be examined as work proceeds.

The actual system, as devised, is a flexible one. Two Soiltest triaxial cells (one six-inch, and one variable 1.4 or 2.8 inch) were purchased for use with a Baldwin Universal Testing Machine. All auxillary equipment is to be mounted on a portable cart such that the test system can be assembled or disassembled quickly without disturbing calibrations and settings. Stress readings will be acquired through a BLH Load Cell, and strain will be monitored by a linear voltage differential transformer. A two-channel strip chart recorder was purchased to record output. Other auxillary electronic equipment (power supplies and meters) will be supplied from the Penn State Mining Section's Rock Mechanics Laboratory. Figure 1 is a block diagram of the load application system, Figure 2 is one of the readout system, and Appendix 1 lists all components including whether they were purchased with project funds or whether they were supplied from existing inventory.

Progress in Assembly

Currently, the project has accepted delivery of the triaxial chambers and associated molds and specimen membranes; the chart recorder; a linear voltage differential transformer (LVDT); and the glycerin container. A siphon for that container has been built; as has a cart for mounting auxillary equipment. On order is the load cell and devices for mounting it and the LVDT into the load frame. Preliminary testing of samples should begin in the beginning of the project's eighth month.

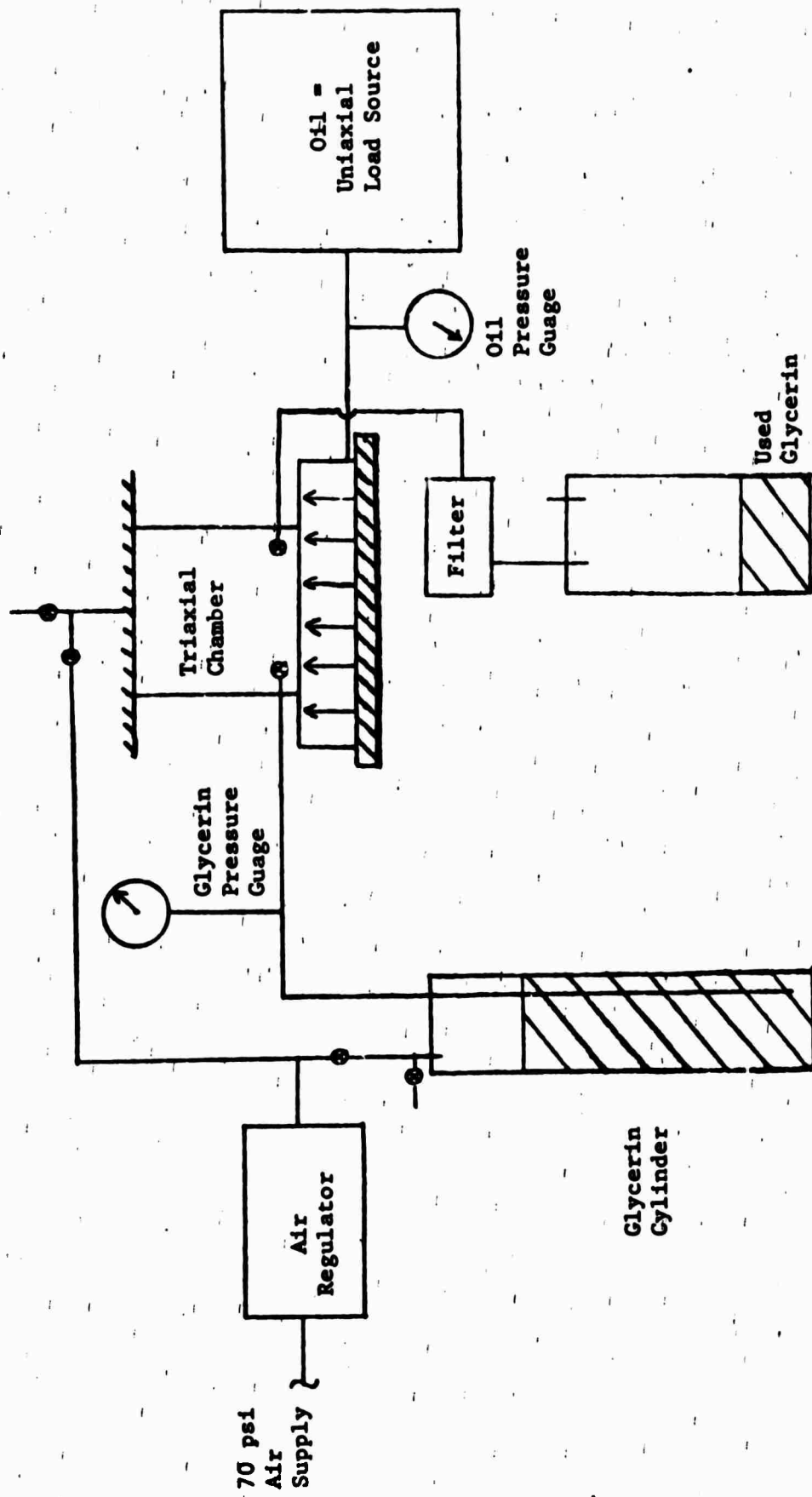


FIGURE 1. BLOCK DIAGRAM OF PRESSURE SYSTEM

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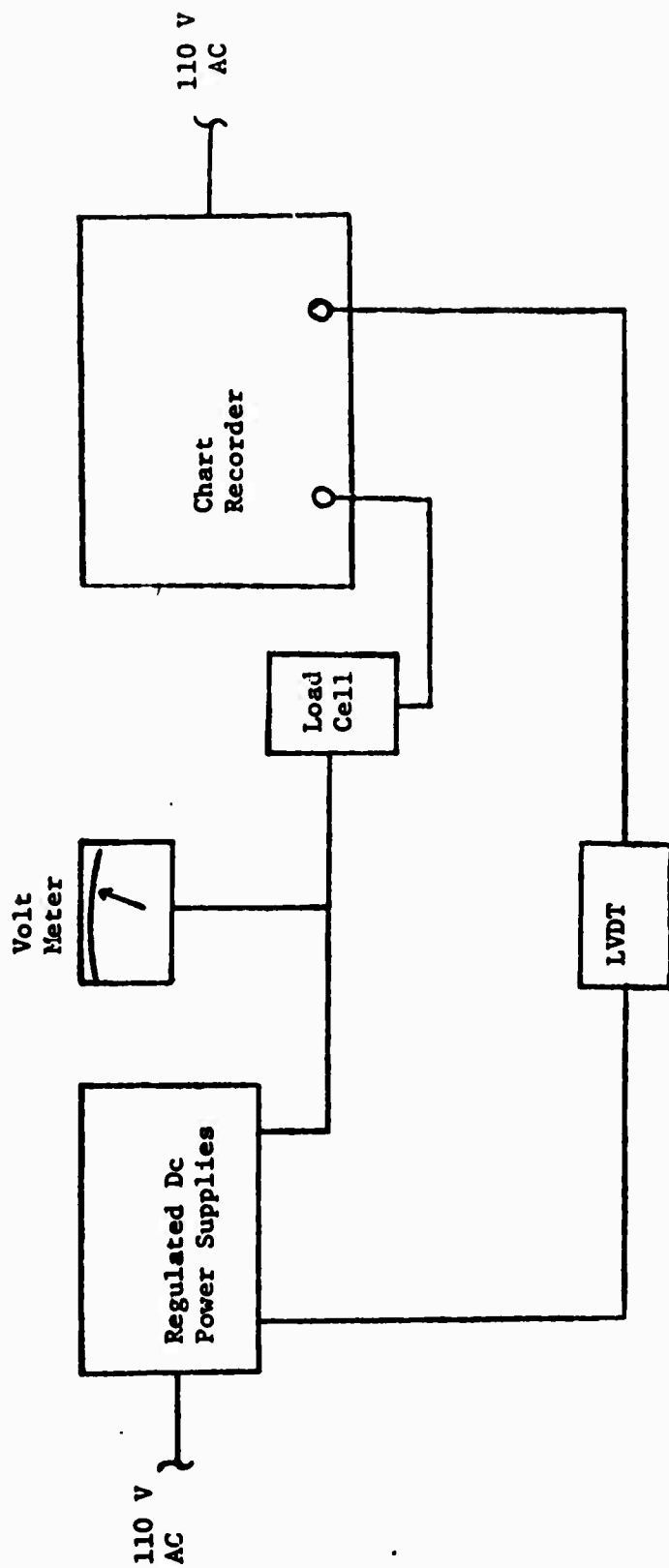


FIGURE 2. BLOCK DIAGRAM OF ELECTRICAL SYSTEM

Tunnel Location

Since the primary mission of this project is to test muck from actual operations, it became imperative to identify active tunneling sites in the United States. There is no central register of these sites, so it was necessary to collect one. The following restrictions were placed on this site identification: the site must be in the Continental United States, it must be machine driven, and it must be in rock. Information was requested from the Bureau of Mines, the Bureau of Reclamation, and seven boring machine manufacturers (Calweld, Dresser, Hughes, Jarva, Lawrence, Robbins, and Wirth). All cooperated and a list of sites was compiled; this is Table 1. Looking at accessibility and degree of completion, nine sites were selected for visit; these are asterisked. Two sites, Washington Metro and the Climax Mine, did not have a machine in operation, but they were nonetheless visited in order to maintain contact and discuss problems, and because they were close to other visited operations. From all available sources, there is no evidence that every major machine-driven tunnel site in rock was not visited.

Collection of Specimens

The Proposed Method

Reviewing promotional literature distributed by tunneling machine manufacturers, it was seen that all machines utilize a conveyor belt to move muck from the cutter head to the tail of the machine. No machine uses any of the proposed fluid transport devices for handling muck. Consequently, the collection of samples reduced itself to the problem of sampling a conveyor belt in confined quarters. It was decided that the most opportune position to sample was at the tail pulley of the machine's conveyor belt, where the muck was transferred to the permanent haulage system. This position would least interfere with the machine's operation,

Table 1. Potential U.S. Hardrock Tunnels

Tunnel Name	Contractor	Diameter	Rock Type	Location	Completion	Machine
San Fernando Water Tunnel	Lockheed	21' U.D.	Variable: Unconsolidated to soft	Newhill Pocerina, Calif.	? soon	Robbins 221 S
* Climax Mine	AMAX (leasing)	12'	Hard	Leadville (Climax) Colorado	Start in April '71	Calweld
* Nast	Bu. Rec. w/ Peter Kiewit	10'	Granitic	Fryingpan Project Aspen, Colorado	?	Wirth
Hunter	Bu. Rec. w/ Granite Const.	10'	Granitic	Fryingpan Project Aspen, Colorado		Conventional
Cunningham	-	?	Granitic	Fryingpan Project	Under bid	Either mole or conventional
* Lawrence Ave.	McHugh Construction	13' 8"	Limestone	Chicago	October 1971	Lawrence
* White Pine	self	18'	Hard Shale	White Pine, Michigan	-	Robbins

(continued)

Tunnel Name	Contractor	Diameter	Rock Type	Location	Completion	Machine
* Foggy Bottom-Rosslyn	Washington Met. area transit auth.	16' 8" I.D.	Schistsgneiss	Washington	Bid opened March 3, '71	Mole ?
* Toronto Interceptor Sewer	S. McNally & Sons, Ltds.	12'	Shale	Toronto	Fall 1971	Robbins 126
* Queen Lane Raw Water Circuit	S & M Contractors	11'	Mica Schist & Quartz	Philadelphia	Aug. '71	Jarva Mark 11-1100
* Navajo Irrigation	Bu. Rel. w/ Fluor Utah Eng. & Con.	20-1/2'	Sandstone	Farmington, New Mexico	April 1972	Dresser
?	Romeo Joint Venture	14' 6"	Soil Formations	Detroit, Mich.	1) July '71 (start) 2) Aug. '71 (start)	Robbins 1435
* Currant Creek	S. A. Healy Co. for BW. Rec.	?	Sandstone	Heber City, Utah	1972	Robbins 141-1

* Tunnels Visited

but would still allow collection of muck before degradation due to further handling upset a sample's validity. Several references on bulk sampling were consulted^{1, 2, 3}; it was obvious that the most important error would be size segregation. This error can be avoided by sampling the entire belt width and by sampling at frequent periodic intervals. Because of the variability of source material due to changing geology, it was decided that one sample should be collected in one time period. There is no apparent way to determine if any segregation occurs in front of the dust shield due to the action of the scoops.

In actual practice, samples were collected at the tail pulley by inserting a square-bladed shovel into the muck stream. If the shovel was not wider than the stream, it was moved back and forth to capture sample from the entire stream width. Sample sacks were of 8-mil plastic and were used double (one inside another). They measure 21 inches by 36 inches flat and are often used to hold 75 to 100 pounds of aggregate. A surplus duffle bag was used to protect and to help transport the sample. A small sample split was put directly into a mason jar in order that water content could be measured. Each filled sack contained over twice the volume necessary for the largest triaxial vessel.

If the machine were down for any reason, but muck was still on the belts, a sample was obtained by cleaning a section of belt completely. If the belts were empty, a sample was obtained from the stockpile. Because of the potential for geologic variation, one sample was taken from one part of the pile. Care was taken to avoid sections of the pile that vehicles had run over. It was felt that this trip was an introduction to machines and operations and that subsequent trips could be more flexible to machine schedules. The less - than - optimum collection of samples from stockpile was accepted because of the pressure to maintain an established itinerary.

Diary of Actual Collection

The principal investigator and one assistant visited nine tunnels under construction. One was being conventionally driven and one had had its machine withdrawn, thus providing no sample. As each tunnel was visited, a data sheet was filled out and a diary maintained. The diary is contained in Appendix 2, and the assembled data sheets in Appendix 3. The first two tunnels were visited independently and the remaining six were visited in one continuous field trip. Samples were shipped in watertight, surplus ammunition cases to prevent degradation. Table 2 is a synopsis of the tunnel visits.

Summary and Conclusions

Future Work

With seven samples in hand and the testing system nearly completed, the remaining effort is easy to postulate. All components of the test system must be calibrated, and then the system itself checked against some standard sand or aggregate. A testing program must be formulated and then performed. This formulation must take into account the potential for sample degradation. The following steps are close to what would be followed.

1. Cone and quarter the sample.
2. Obtain sieve analysis of one half of the sample and retain size fractions for triaxial test.
3. Perform triaxial test on the other half of the sample.
4. Perform triaxial tests on the individual size fractions.
5. Compare ϕ amongst the individual size fractions, and also against that for the combined sample.
6. With at least one sample, compare ϕ as determined from three different cell diameters.
7. With at least one sample, compare ϕ as determined by triaxial cell and by the shearbox tester at the Pittsburgh Mining Research Center.

Table 2. Tunnel Locations and Data

	Phila- delphia	Chicago	Heber City	Farming- ton	Aspen	White Pine	Toronto
Date of Visit	6-24-71	7-16-71	7-19-71	7-21-71	7-22-71	7-26-71	7-27-71
Outer Diameter	11'	13' 8"	12' 11"	20' 6"	10'	18' 2"	12'
Lined Diameter	8'	-	10' 4"	18'	Only in Bad Ground	Unlined	10'
Length to Date	4100'	19,500'	1200'	1700'	2800'	4800'	2-1/2 mi.
Length Total	5800'	22,000'	17,355'	3.5 mi.	16,800'	2 mi.	15,200'
Best Shift	40'	49.4'	67'	65'	40'	24'	?
Best Day	89'	111.3'	176'	178'	60'	44'	?
Number of Men	4	7	6	12	8	6	?
Machine	Jarva Mark 4	Lawrence 0007	Robbins 141-127	Dresser	Wirth	Robbins 181-122	Robbins 126
Horsepower	500	750	600	700	600	800	500
Cutters	27 disc kerf	27 disc w/button mount	29 disc	36 double disc	26 button roller	47 disc	25-30 disc
Rotation RPM	10	9	3 or 6	6	8	4.5	5-10
Thrust	1,200,000	1,500,000	750,000	850,000	1600 psi pump pressure	1,200,000	?
Spray (GPM)	5	40	2-3	None	26	15	?
Conveyor Width	18"	24"	30"	30"	24"	30"	?
Rock Type	Mica Schist	Dolomitic Limestone	Sand- stone	Sand- stone	Granite	Sand- stone	Shale
Sample % Moisture	14.926	8.411	14.447	-	21.975	-	-

8. Retain all samples.

Completion of these steps would signal performance of the contacts however several contracts were made during the sample collecting trip which should be pursued. If funds remain in the present budget, and if the testing program is in satisfactory condition, then it is proposed to revisit one or two of the tunnel sites. The intention would be to acquire multiple samples under varied boring-machine operating conditions.

Observations

It may be useful to note here some general observations about the tunnels visited. The successive visitation of eight tunnels made certain inefficiencies very obvious. For instance, it was clear that those machines with disc cutters had fewer problems than those with rollers. The discs had fewer problems with insert breakage; they produced larger chips; and they cleared themselves of muck better. A reasonably direct comparison can be made between the Philadelphia tunnel (mica schist, discs) where the operator was happy with his progress and the Nast tunnel (granite, rollers) where the operator was disappointed with his progress.

A recurring problem was the inability to clean material that had sloughed from the walls behind the cutting head. This material would accumulate in the invert and require hand mucking in very cramped quarters. Provision for mucking behind the cutter head, say with a small slusher, should be provided.

Another problem was the source of the sloughed material. In certain rock types the grippers acted as indenting punches, such that when they were retracted a conical volume of rock would fall out. To avoid the problem of stress concentration, these pads should be smooth and of as broad an area as is consistent with mobility and reliability design.

Of course there were other problems observed, such as the problem of continuity of experience under the contracting system, but they were not of an engineering variety.

Conclusions

Obviously, no direct conclusions can be made at this time on the testing program. Some conclusions, or more properly observations, can be made on the mechanically-chipped material that was collected. All the fine-grained rocks which were observed produced long shard-like chips. Each of these rocks, limestone, sandstone, and shale, were cut by discs. The maximum length of these shards often exceeded the postulated two inches. The more coarsely-grained rocks, granite and mica schist, produced a very fine material. Although the cutter type may influence the shape and size of the chipped material, it is apparent that the rock type exercises the greatest influence. It was also clear that the larger size material had preferable handling characteristics; this was because it did not jam at transfer points and because it did not retain water. Inasmuch as the fine-grained material produced from granite did retain water, there may be cause for investigating hydraulic methods for its transportation. It will be interesting to provide a quantification of these observations during the next portion of the program.

Inventions

None of the work performed to date provided an invention or discovery of a patentable nature.

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APPENDIX I
EQUIPMENT LIST

Main cell 6" x 12" USDI-0027 5-65099⁺ - Soiltest
 Smaller main cell 2.8" x 5.6" USDI-0027 5-67502⁺ - Soiltest
 Large metal cylinder w/tubing connections 6" x 15" 5-65100⁺ - Soiltest
 Psi pressure gauge 5-67501 - Ametek
 Small metal cylinder w/tubing connections and clamps 3" x 7.5"
 USDI-0027⁺ 5-67503 - Soiltest

(Supplies for above)

1 Chart recorder - Hewlett-Packard
 10,000 lb. U3G1 BLH Load Cell
 Glycerin Tank, Oxygen Surplus, and Siphon
 Storage Cabinet USDI-0027 5-67525⁺
 Cart for chart recorder, Glycerin Tank etc.

- * Linear variable differential transformer
- * DC power supplies
- * B & F output conditioner monitor
- * Volt meter
- * Microampere meter

⁺ USDI Inventory Number

* Supplied by Penn State Mining Department

APPENDIX II
A DIARY OF SAMPLE COLLECTION

Queen Lane Raw Water Conduit

On Thursday, June 24, 1971, samples of tunnelling machine cuttings were collected by L. W. Saperstein and T. E. Wilson. A one-quart mason jar sample was collected for percent moisture determination, and approximately 60 lbs. of cuttings were collected as a bulk sample.

Location of the tunnel portal is at Ridge Avenue and Schoolhouse Lane, Philadelphia. At the time of collection, the footage of tunnel advance was 4100 ft. (Total length of tunnel will be 5800 ft.; the tunnel will connect to a vertical shaft). The tunnel is circular, with an excavated diameter of 11 ft. Grade of the tunnel (in bound) is +1% for the first 3000 ft., and +3% thereafter. The tunnel has several turns, corresponding to street location at the surface. Depth of cover is 50 to 105 ft. The purpose of the tunnel (to be concrete lined to 8' ϕ) is for raw water transfer from the Schuylkill River inland.

The rock type is a very micaceous Mica-Shist (Muscovite, Biotite, Phlogopite) with occasional lenses and stringers of fine-grained quartzite (less than 5% by Vol. Quartzite). The rock is friable and easily degraded; cutting are 100% minus 2", and 90% minus 6 mesh, approximately. At the point where the sample was taken, the digging was reported to be easy (i.e., few or no quartzite stringers encountered). However, the presence of quartzite was reported to have no effect on the size consist of the cuttings.

The samples were removed from the 18-inch width muck discharge conveyor of the tunnelling machine; one 5 ft. long, 5 inch depth (approx.) continuous section of conveyor burden constituted the samples.

The tunnelling machine is a "Reed-Jarva Mark 14" machine.

Tunnel constructors were S & M Construction Company, under contract to the city of Philadelphia.

Washington, D. C. trip

June 8, 1971

Dr. Saperstein and Paul Bilzi left State College about 7 a.m. for Washington, D. C., for the purpose of inspecting a tunnel site owned by the Washinton Metropolitan Area Transit Authority.

They arrived shortly after 11 a.m. and went first to the main Metro Building in L'Enfant Plaza. General aspects of the Metro were discussed with Mr. John Ansley, Assistant Director, Office of Construction.

The Metro is an extensive underground subway system, with its lines running radially from the center of town. Much of the system will be underground, with the parts in the suburbs above ground or in trenches. When completed, trains will be controlled from a central building, with only one company rider aboard each train for safety and emergencies. Scheduled completion date for the system is 1979.

The portions of the system which are using cut and cover are expensive and problematic, because they must dig from building face to building face, so have to shore up the buildings.

Foggy Bottom-Rosslyn contract has just been awarded. It will be constructed by a joint venture of S & M, Ball, and Shea.

There will also be an earth tunnel starting in a couple of weeks. This will be dug by Mimco and American Structures, and will be a twin tunnel, steel and concrete lined.

After lunch, they travelled to Rock Creek tunnel, being constructed in Rock Creek Park in N. W. Washington. They were given a tour of the tunnel by Mr. Lee True, resident engineer who is overseeing the work being done by S. A. Healy Company.

The tunnel is in about 750' out of 4000' total. It is being advanced by conventional methods.

The drilling and blasting scheme utilizes a burn cut. There are 103 holes drilled in the face. Each hole is drilled to 10', and pulls about 8'.

Drilling takes a little over an hour. There are 13-drifter mounted drills total, but they only use 6-8 at a time.

There are two shifts each day, and they drill and blast once each shift. Average advance is 15' per day, or 75' per week.

Mucking is done by one front-end loader and several LHD's. At present, muck is loaded and carried immediately out of the tunnel. When the tunnel gets further in, muck will first be moved out of the way of the drill face, and then picked up and moved out of the tunnel. No truck haulage is planned.

Lining is shotcrete applied in three layers. The first layer is applied immediately, the second about 150' from the working face, and the third later.

This 4000' section of tunnel will terminate under Dupont Circle, where a station area 79 feet wide will be dug.

Chicago, Illinois

July 16, 1971

Lawrence Ave. Sewer Tunnel

The investigators visited the Lawrence Ave. Sewer Tunnel at 2920 W. Lawrence Ave., in North Chicago. This job is being done by James McHugh Construction Company, S. A. Healy Company, and Kenney Construction Company. McHugh has the primary operating responsibility. They spoke with Bob Cain and Bill Harriett, and Bill took them underground. Bill Burton, the main foreman, was not on the job that day.

Chicago has a combined waste and storm sewer system. During heavy rains, the present system is inadequate to handle the flow. The Lawrence Ave. Tunnel will act as a reservoir, holding the flow until the treatment plant can handle it.

The tunnel is being bored in very competent dolomitic limestone. This limestone is flat-lying so rock bolting is advisable to strengthen the roof,

but otherwise it is excellent rock to bore. Entrance to the tunnel is a shaft, 255 feet down through 40 feet of overburden, the rest rock. The tunnel is in about 19,500 feet. with about a half mile to go. When the tunnel is finished, the machine will be withdrawn up a shaft which is yet to be sunk at the far end of the tunnel. If the shaft for some reason is not completed, the machine will have to be dismantled and backed out.

The machine currently being used is a Lawrence 007. This is the second machine in the tunnel. The first machine burned out, so was removed. It gave them particular trouble, since it was guided by a pilot borer, whose bearings wore out fast. This would cause the machine to wander.

The 007 is also guided by a pilot borer, but its bearings are designed much better. Alignment is by a laser on a target.

The present machine was brought in and first bored the 5000' Hastings Rd. feeder tunnel. While it worked, the Lawrence Ave. Tunnel was advanced 2400' by conventional drill and blast. Then the mole was brought into the main tunnel, where it was seen.

The drill-blast part of the tunnel is 19-1/2' high by 15-1/2' wide, which equals the volume of a 17' diameter round hole. The portion of the tunnel which was bored by the old machine was 13' 8", but was also blasted out to the bigger diameter. This part of the tunnel is concrete lined. The rest of the conventional and the bored part will probably not be.

At one point there is a 500' radius curve, in order to follow under Lawrence Ave. This was originally supposed to be 180' radius, but the machine plus gantry could not make it.

Muck comes off a conveyor into rail cars. It was at this point where they did their sampling. Rail haulage is to the shaft, where the cars pull under a big hook, and are lifted off their dollies.

The shaft is 2-compartment; one a muck skip, the other the man cage.

Muck is tripped from the skips into a large hopper, then loaded into trucks. If trucks are late, muck may be dumped on the ground and pushed into an auxilliary pile until it can be moved later.

They took a moisture sample and bulk sample from the end of the conveyor in the tunnel, and a bulk sample from the outside muck pile.

Heber City, Utah

July 19, 1971

Strawberry Aqueduct, Layout Tunnel

The tunnel site is located 40 miles east of Heber City, north of U. S. 40 on Currant Creek Road. It is part of the massive Central Utah Project, on which we have written for data to the Bureau of Reclamation.

The purpose is to take water from Layout Creek and the proposed Currant Creek Reservoir and feed it into the Strawberry Reservoir, which is a water source to Salt Lake City and north central Utah.

The Water Hollow Tunnel is complete, having been a joint effort of Gibbons and Reed and Boyles Brothers. Both the Layout and Currant tunnels have been contracted to S. A. Healy; they are working now on layout and when finished will proceed to Currant.

We were on the site from 10 a.m. to 1:30 p.m. We spoke initially to Mr. Robert Ames. John Wagner, Chief Engineer for Healy took us underground and answered our questions.

The machine is a Robbins 141-127. It has a laser guide, which can last 2-3000 hours. The machine was also equipped with a shield.

When we were there they were into some very bad ground; wet conglomerate and clay in a fault cone. In this ground they were making only 20' a day.

The grippers would not grip in the soft ground, so they were throwing timber behind the grippers in attempt to gain friction. They were also forced to line the bad ground area with steel ribs. This presented quite a problem because of general inaccessibility around the machine.

Muck was loaded into railway cars and hauled to a pile a short distance outside the portal. The cars were side-dump.

Muck movement in the bad ground was inhibited by the water content. Mud had built up between the rollers and the conveyor, so instead of getting traction the rollers were spinning and the belt was barely moving.

The company was about ready to shut down to install a longer gantry for loading the trains.

A moisture sample was taken from the conveyor belt, and a bulk sample from the outside muck pile.

Farmington, New Mexico

July 21, 1971

Navajo Irrigation Project

The tunnel site is located about 16 miles east of Bloomfield, N. M. It is part of the Navajo Irrigation Project, a project to bring irrigation water to the Navajo Indian Reservation to the southwest.

Two tunnels and a siphon are contracted to Fluor Utah Company. The present tunnel is in 1700' out of a total of 3.5 miles.

Our questions on the project were answered by P. E. "Joe" Sperry. We were taken underground by Jay Terry, Safety Engineer.

The machine used is a Dresser with a 20' 6" head. It was by far the roomiest tunnel we had been in in terms of access to the machine. Besides the normal walkways along side of the mole, it had a full work deck situated atop the gantry. Trailing behind the mole was a 600' platform on rails, which was itself the rail switches for the cars. This eliminated the need for a California switch elsewhere in the tunnel.

The machine is laser aligned, visually sighted. Muck is handled by a conveyor, then dumped through a tipple to easily load the long (16 yd³) cars. The tipple is controlled by an operator watching it on closed-circuit

television. Muck is taken out to a large pile, where it is spread by a front-end loader.

The tunnel was formerly in competent sandstone, which made it very dry since no water spray is used. The tunnel was presently in a lense of wet shale, into which they had bored about 200' and expected to be out of soon. In the meantime, the operation was down awaiting shotcrete equipment. This was to be placed on the upper work deck, in hopes of containing the bad ground without having to go to steel ribs.

Because it was down, no moisture sample was taken. The bulk sample was taken from the outside muck pile. It is very crumbly sandstone, so will deteriorate; hence, the size will be indeterminate.

Meredith, Colorado

July 22, 1971

Fryingpan Project, Nast Tunnel

The tunnel site is about 8 miles east of Thomasville, Colorado, very near the Continental Divide at about 10,000' above sea level. We were taken into the tunnel by Wilbert Steele, Safety Engineer.

The tunnel is part of the major Fryingpan-Arkansas Project, which is to divert water from the Fryingpan drainage basin east across the Continental Divide into the Arkansas River, where it will eventually go to Colorado Springs and eastern Colorado. Only water above 10,000' may be taken from the Fryingpan basin. Below that it will be left to drain into the Fryingpan River and Ruedi Reservoir.

Peter Kiewit Sons have the contract on the Nast Tunnel. No contract has been let on Cunningham yet, and may not be until 1973.

The machine is a Wirth, and according to the guide they have had great trouble with it. Many welds are only one pass, so they simply come apart. The machine has an awkward shield, which is entirely unnecessary

in the competent granite.

The cutters will not cut the rock; the buttons break off at the casing. The operation was down for a cutter change while the investigators were there.

Mucking is by conveyor belt mounted on a muck master. It is a belt supported by frames on the track. These are movable, and when the train comes in, they are pushed back behind the train, and the conveyor is supported atop the cars.

Muck is dumped and spread by a front end loader. It is used as road material for their access roads.

The machine uses so much water, the rock comes out very wet. It is sent through a series of settling ponds to clean up the water.

We took a moisture sample from the first settling pond, and a bulk sample from right alongside it.

The Nast Tunnel is very beset with problems.

Climax, Colorado

July 23, 1971

Climax Molybdenum Mine

The investigators spent almost a full day at Climax. They were extremely helpful. They spoke above ground with Bob Elder, head of Industrial Engineering. Mike Gibson, a mechanical engineer, took us underground.

Climax had had a Calweld machine, but had given up on it. It had bored a 1000' drift, when the gauge cutters failed. They were replaced, and in 10' were destroyed again. Climax and Calweld then mutually terminated their contract.

The first drift was in porphyry of 15-18,000 psi. The later drift was in rock of an average 20,000 psi.

The first drift was 13' in diameter, and the major problems were in materials handling. The machine produced spalls, which jammed in hoppers and tore belts. The grippers had trouble in soft ground. Often fracture resulted at the points where the grippers had been when they were removed.

Scrapers and scoops at the face wore rapidly, which produced large cutter wear. Almost every day the scrapers had to be built up. Finally Calweld came out with a spring-loaded scraper which worked better. The cutters on the machine were button roller.

The muck was very fine and slushy, so it hung up in skips and shafts, making it very difficult to handle. It collected on the floor 18-30" thick, which ultimately had to be mucked out by front end loader, which took 4 months. The Calweld machine did not seem to take into account the fact that in a mine you cannot devote all your time and effort on one level to the operation and handling of muck from a single machine.

Cost of the initial moling was three times normal conventional costs. One bright spot was support; it only cost half of conventional. The strongest support used were 4" I beams with 5' centers, full circle, with 3 x 12 lagging. Most support however, was just random rock bolting, with some ground even unsupported. Future maintenance of the drift will also be cheaper than conventional ones.

Handling track and equipment was by a monorail alongside the machine. Mucking was by 6-car train.

White Pine, Michigan

July 26, 1971

White Pine Copper

White Pine Copper Mine is located on Route 64, White Pine, in the upper Michigan peninsula just south of Lake Superior. We spent most of the day with Cliff Hanninen and Jerry Bennett, of Mine Research. We also spoke for a short time with Joe Patrick, a Vice President; and Bill Lane,

Bore Supervisor.

The tunneling machine, a Robbins, is boring a 2 mile ventilation and electrical tunnel. The tunnel is 110' under the ore syncline, so it goes down and will come back up an average 10% grade. It has bored on a 20% downgrade.

Boring is presently in sandstone, 25,000 psi, 60% silica content. The machine uses disc cutters and is getting quite large breakage pieces.

The tunnel will connect their eastern shaft with the main mine. There is a travelway above it in the orebody. Every 1000 ft. or so a raise will be bored to the travelway for ventilation. Also, the machine tunnel gives good access for testing the orebody.

This tunnel was the most efficient observed. Best looking muck, best costs, and best materials handling - a conveyor belt all the way from the machine to the shaft all were seen.

White Pine has a large rock mechanics section, and runs extensive tests on samples. They have been mining since 1955, and have a large orebody, avg. grade 1.4% CuS_2 .

We took no moisture sample, because machine was down for cutter change. A bulk sample was collected from an outside muck pile.

Toronto, Ontario

July 27, 1971

Mid-Toronto Interceptor Sewer

The tunnel site visited was at 500 Gerrard Street, although the tunnel runs about 2-1/2 miles through east Toronto. The investigators spoke to John MacKay, who was good enough to come out at 7:30 p.m. to show them around.

The purpose of the tunnel is to collect sewage and water from East Toronto, and to hold it until the treatment plant on Lake Ontario can handle it. The sewage system in Toronto, like in Chicago, is combined

storm and waste.

While they were there, the machine was down. It had bored about 2-1/2 miles, then an area was dug by cut and fill. At the time they were there, the machine was being lowered down a shaft to complete about 2000' of tunnel. The machine had to be broken only into 2 pieces to be lowered.

The maximum depth of the tunnel is 90', with minimum depth of 30' under the river. Concreting is done over a length of 150' (5 forms of 30' each). Eventually whole tunnel will be lined. Mucking is by rail.

The biggest problem is materials handling, as they cannot handle the muck as fast as it comes off the face. MacKay claims they have had no trouble with the grippers breaking the wall rock.

APPENDIX III
ASSEMBLED DATA SHEETS

Location No. 1Sample No. 1Date June 24, 1971

Data Sheet
Big Hole Drilling Project

Location Data: Location Philadelphia - Ridge Ave. & Schoolhouse Lane
 Owner of Tunnel City of Philadelphia
 Drilling Contractor S & M contractors
 Person in contact with Ron A. Marra

Tunnel data: Name of Tunnel Queen Lane Raw Water Conduit
 Diameter 11' O.D lined to 8' (will line after mining)
 Length to date 4100' out of 5800'
 Best Shift 40'
 Best Day 89'
 No. of men in tunnel 4 men + locomotive operator

Machine data: Machine name and no. Jarva Mark 14
 Horsepower 4 @ 125 hp each
 Type of cutter Disc kerf w/gauge teeth 27 total
 Rotation speed 10 rpm
 Thrust against face 1,200,000 #max 1,150 #/in actual
 Thrust cylinder diameter 4-1/4" 8 cyl. fluid pressure
 Water spray? yes Amount 5 gpm Type pure H₂O
 10.8'/hr. at operating pt. Rate of advance soft 16'/hr. qtz. 7'/hr. low 4-5'/hr.
 Size of conveyer belt 18"

Rock data: Approx. amt. of sample 75 lb.
 Core available? no
 from so-called soft material Present type of rock mica schist w/qtz. bands
 Compressive strength 15,000 min - 25k avg. - 35 max

Other comments: Laser Aligned - Spectra - Physics, testing different thrust pressures, little overbreak, 55-105' of cover.

Location No. 2
 1 = outside
 Sample No. 2 = inside
 Date July 16, 1971

Data Sheet
 Big Hole Drilling Project

Location Data: Location 2920 W. Lawrence Ave. Chicago
 Owner of Tunnel City of Chicago
 Drilling Contractor James McHugh also S. A. Healy
 (Kenney)
 Person in contact with Bob Cain, Bill Harriett

Tunnel data: Name of Tunnel Lawrence Ave. Sewer Tunnel
 Diameter 13' 8"
 Length to date 19,500' 1/2 mile to go
 Best Shift 49.4' (long shift)
 Best Day 111.3'
 No. of men in tunnel 3 machine operators & 4 labor

Machine data: Machine name and no. Lawrence 007
 5 houdailk motors Horsepower 3 @ 250 hp for main drive
 Type of cutter 27 disc w/button inserts
 Rotation speed 9 rpm (pilot = 30 rpm)
 pressure = 1700-1800 psi Thrust against face max = 1.5×10^6 lbs. (75% = avg)
 Thrust cylinder diameter ?
 Water ^{no spray} ~~spray?~~ ^{pilot & air} ~~scrubber~~ Amount 40 g/min Type
 Rate of advance 20'/shift 60'/day
 Size of conveyer belt 24"

Rock data: Approx. amt. of sample 75 lb. inside 90 lb. outside
 Core available? no
 Present type of rock dolomitic ls. flat-lying
 Compressive strength 16 - 23,000 psi

Other comments: large chamber 19-1/2' high x 15-1/2' = volume of 17' dia.

Data Sheet

Big Hole Drilling Project

Location Data: Location 40 mi. east of Heber City, Utah off US 40
5 mi. N. on Currant Creek Rd. (gravel)

Owner of Tunnel Bureau of Reclamation

Drilling Contractor S. A. Healy

Person in contact with Robert Ames, John Wagner

Tunnel data: Name of Tunnel Layout Tunnel (Currant Tunnel later 9100')
Strawberry Aqueduct

Diameter 12' 11" concrete later to 10' 4"

Length to date 1200' out of 17,355'

Best Shift 67'

Best Day 176'

No. of men in tunnel 6 optimum up to 15 in bad ground

Machine data: Machine name and no. Robbins 141-127

Horsepower 600

Type of cutter 29 disc

Rotation speed variable 3 or 6

Thrust against face up to 750,000 lbs.

Thrust cylinder diameter 4 @ 9" ea.

Water spray? 2 small sprays Amount 2-3 glmin. Type

Rate of advance

Size of conveyer belt 30"

Rock data: Approx. amt. of sample 100 lbs. from outside muckpile

Core available? no

Present type of rock conglomerate & clay formerly competent ss

Compressive strength ss = 5-10,000 psi 23,000 right at portal

Other comments: Main sample from outside due to present bad ground
mositure sample from conveyer belt

also 2-3 glmin for
air scrubber

Location No. 4Sample No. 1Date July 21, 1971

Data Sheet

Big Hole Drilling Project

Location Data: Location S. of Bloomfield, N. W. on Rt. 44, left just past river 12 miles to dirt road, right 4 mi.Owner of Tunnel Bureau of ReclamationDrilling Contractor Fluor UtahPerson in contact with P.E. "Joe" Sperry, Jay Terry Safety Engr.Tunnel data: Name of Tunnel Navajo Irrigation Project #3machine head can vary
down to 16'Diameter 20' 6" will concrete to 18'Length to date 1700' out of 3.5 milesBest Shift 65'Best Day 178'No. of men in tunnel 12Machine data: Machine name and no. DresserHorsepower 700 hp DC 4 motors @90 hp ea. run at twice speedplum bob bits in center
of head Type of cutter 36 double disc or button insertRotation speed 6 rpm (variable 2-10, 6 is best)1100 psi to move
cutter head 70,000
lbs. to move floor Thrust against face 850,000 lbs. (3000 psi/cyl)
(455 in 2 total)Thrust cylinder diameter 4 @ 11" ea.Water spray? No Amount Type Rate of advance 3"/min. = 15'/hr.Size of conveyer belt 30"Rock data: Approx. amt. of sample 80-90 lb. ssNo moisture Core available? noPresent type of rock wet shale - formerly ssCompressive strength 3000 psi for ssOther comments: Sample of ss from outside muck pile - sample is quite crumbly, size will be indeterminate, muck dropped through tippie then spread by front-end loader.

Data Sheet

Big Hole Drilling Project

Location Data: Location 8 mi. east of Meredith, Colo.Owner of Tunnel Bureau of ReclamationDrilling Contractor Peter Kiewit SonsPerson in contact with Wilbert Steele, Safety Engr.Tunnel data: Name of Tunnel NastDiameter 10', will line only in bad groundLength to date 2800' cut of 16,800'Best Shift 40'Best Day 60'No. of men in tunnel 8Machine data: Machine name and no. WirthHorsepower 3 @ 200 hp driving hydraulic pumpsType of cutter 26 button rollersRotation speed var. to 14, est. operating at 8 rpmpump pressure 1000-2200 var.
Thrust against face psi. est. operating 1600 psi.Thrust cylinder diameter ?Water spray? Yes Amount 26 glmin. Type Rate of advance ?Size of conveyer belt 24" (32" on muck master)Rock data: Approx. amt. of sample 80 lb.Core available? noPresent type of rock graniteCompressive strength 30,000 psi (guess)Other comments: Machine down for cutter change, most recent muck mined 4 hrs. previously, water sample from 1st settling pond, may be over-wet due to decant fluid.

Data Sheet

Big Hole Drilling Project

Location Data: Location Rt. 64, White Pine, Mich.
Owner of Tunnel White Pine Copper Co.
Drilling Contractor White Pine Copper Co.
Person in contact with Cliff Hanninen - Mine Pres.
Bill Lane - Bore Supv.
Jerry Bennett
Joe Patrick - Vice-Pres.

Tunnel data: Name of Tunnel _____
Diameter 18' 2"
Length to date 4800' out of 2 mi.
Best Shift 24' - 8 hrs.
Best Day 44' - 2 shifts
No. of men in tunnel 6 in boring shift, 8 in maintenance
(day shift)

Machine data: Machine name and no. Robbins 181-122
40% Horsepower 800 reduced from 1200 hp
Type of cutter 47 disc + 1 center tri-disc
Rotation speed 4-1/2 rpm
Thrust against face 1,200,000 lbs.
Thrust cylinder diameter ?
Water spray? Yes Amount 15 glmin. Type 11 nozzles
Rate of advance 4'/hr. or 18'/day or 360'/ mo.
Size of conveyer belt 30" on machine, 36" main line

Rock data: Approx. amt. of sample 80 lb. ss. from outside muck pole
Core available? no
No moisture sample Present type of rock ss.
Compressive strength 25,000 psi

Other comments: Driving down # dip avg. 10%.

Location No. 7Sample No. 1Date July 27, 1971

Data Sheet

Big Hole Drilling Project

Location Data: Location 500 Gerrard Street, TorontoOwner of Tunnel City of TorontoDrilling Contractor S. McNally & SonsPerson in contact with John MacKayTunnel data: Name of Tunnel Mid-Toronto Interceptor SewerDiameter 12', concrete to 10'Length to date 2-1/2 miles so far, about 2000' to goBest Shift ?Best Day ?No. of men in tunnel ?Machine data: Machine name and no. Robbins 126Horsepower 4 @ 125 hpType of cutter 25 - 30 discRotation speed 5 - 10 rpmThrust against face ? probably under capacityThrust cylinder diameter ?Water spray? ? Amount Type Rate of advance ?Size of conveyer belt ?Rock data: Approx. amt. of sample 80 lbs.No moisture sample Core available? ?Present type of rock shaleCompressive strength 5000 psiOther comments: Sample from outside muck pile, has been there some timeBiggest problem in tunnel is materials handling.